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SOME CONSIDERATIONS OF TACTICAL SENSORS FOR TARGET DETECTION, LOCATION AND RECOGNITION

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Abstract

AGARD Project 2000 is examining the match of military requirements and technology for use about the end of this century. As a part of this effort, Study Group #3 headed by John Entzminger of RADC, is undertaking a dialog on target detection, location and recognition between representatives of the operational military users and sensor technologists. The objective is to consider military needs and prospective technological capabilities to jointly speculate on the most valuable system forms for development. This paper was prepared to aid the discussion and attempts to:

- summarize the user aspects of current sensor technology
- suggest some directions in which sensor capabilities might be developed
- point out the capabilities and limitations of the generic sensor forms.

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I. INTRODUCTION

The objective of this paper is to summarize the generic forms of sensors which are applicable to airborne detection, location and recognition of ground targets and to outline the broad sensor capabilities and limitations as one basis of dialog between operational military users and sensor technologists. The value of sensor reports and the survivability of sensor platforms are critical judgments in sensor selection but are principally operational questions. Since this paper is written from a technology perspective, some of the relevant aspects are pointed out but no conclusions are drawn in such areas.

No one sensor can be expected to provide all the information which is required. Some will fairly readily, and in some cases automatically, detect regions of interest and their reports can be used to bring other sensors, with more detailed capability, to bear on this limited area (i. e., perform a "cueing" function). Since, in general, sensor types which cover a very large area cannot simultaneously provide the fine-grained information often necessary for recognition, this suggests a two-(or multi-)stage, "zoom" approach. This may take the form of independent sensors or, in some cases, a single multimode sensor.

In most cases, the closer the sensor is to the target, the more detail it can provide. It may, therefore, be appropriate to consider both "standoff" sensors (operating over friendly-held territory) and "penetrator" sensors (operating over enemy-occupied areas). In any case, it is convenient to deal with sensor classes in terms of the range from the sensor to the targets of interest.

The jamming vulnerability is another important factor which is range sensitive. In general, it is much more difficult to jam sensors which are observing targets at shorter ranges.

An effective and robust system for detection, location and recognition of targets is, therefore, likely to have a mix of sensor types. Some of the tradeoffs to be considered which are a function of range, are summarized as follows:

Long range: - Broad area coverage
- Presumably less vulnerable to physical attack
- Data links can be protected

Short range: - More detailed information
- Sensors less easily jammed
- Less terrain masking

All of the above remarks are broad generalities and there are, of course, many exceptions. Nonetheless, the principles appear to generally valid and provide a useful basis for discussion.

The following sections examine the broad capabilities and limitations of sensors applicable for various ranges to the target. This is not intended to be a comprehensive description of all sensors but rather a general discussion of the most important sensor classes.

One limitation on the discussion to follow is perhaps worthy of note. This paper deals only with what might be called "pure" sensors* whereas many real sensor systems are likely to utilize combinations or hybrids of these. For example, a synthetic aperture radar (SAR) may have moving target indication (MTI) capability and modern MTI radars will probably have limited SAR or doppler beam sharpening modes. While any combination can be designed and built, this will generally entail a compromise of performance and higher cost. In a practical sense, a sensor will be designed for a primary purpose and will have limited capabilities in its auxiliary modes. Therefore, in the example mentioned, one should decide in each case whether the need is for a SAR with limited MTI or an MTI with limited SAR; these will be quite different sensor systems and should not, in general, be viewed as equivalent.

*Some of the more important auxiliary modes directly associated with each sensor class will be mentioned.

This is not to say that a sensor system cannot or should not be built which has the full capabilities possible in each of two or more modes, just that it often is not. In fact, in considering total-system, life-cycle costs, use of a very capable, multi-mode sensor may well be the best approach in some cases.

One class of sensors should be mentioned but will not be discussed, namely the "bistatic" active sensor wherein the transmitter and receiver are not colocated. The capabilities of such sensors are generally similar to the corresponding monostatic implementation but one can trade the added complexity for potentially improved survivability.* The latter is based on locating the radiating portion where it is difficult to attack and keeping the receiving element hidden by virtue of covertness; an additional benefit of receiver covertness, if it can be achieved, is the extra difficulty of jamming a receiver when its location is not known.** In any case, the bistatic configurations can be considered more or less as special-case variations of the monostatic versions. The foregoing remarks generally apply to surveillance applications. One other important form of bistatic configuration of interest is the standoff-transmitter, "kamikaze"-receiver which might be considered a special case of terminal homing.

*There are instances where bistatic configurations may also offer performance benefits.

**This covert-receiver approach will help against narrow-beam tracking jammers but not against broad-angle, sector jammers.

II STANDOFF - TARGET RANGES TYPICALLY 10-200 KM

Standoff sensors will be considered for aircraft platforms operating typically in the 0-30 km altitude regime. Standoff should also include sensor observations from satellites in synchronous orbit (range 4×10^4 km) and near-earth orbit (ranges typically 500-1000 km). However, satellite sensors are a special class which will not be dealt with in this paper beyond the limited remarks of this paragraph. Sensors located in synchronous orbits could provide continuous observation of a region of interest but must overcome, in terms of resolution and detection, the extreme distance and lack of relative motion. Near-earth orbit platforms could be considered for most of the sensors which are discussed for standoff aircraft and are useful for vertical observations such as high-resolution photography (weather permitting) but the system must accommodate the low revisit rate for any region of interest.

The sensors which are generally applicable to ranges of 10-200 km are:

- Synthetic aperture radar (SAR)
- Moving target indicator (MTI) radar
- Foliage penetration radar
- Emitter location systems (ELS) for use against intentional RF radiations.

Each of these will be discussed.

These classes of sensors, used at standoff ranges, have some common characteristics including the following:

- Sensors must be operated at relatively high altitude since they require essentially direct line of sight to the target. As a general guide, to search for targets at 200 km range, one

would use approximate sensor altitudes of 13 km in the European Northern Plains or 23 km in the Central region*; likewise, for targets at 100 km range, the respective altitudes would be approximately 6 and 11 km.

- Survivability depends on standoff distance, altitude, platform performance and protection. Typically, one might locate a sensor such that approximately half its range coverage extends over the enemy side of the FEBA (i.e., a 200 km sensor located 100 km from the FEBA) although this is obviously a trade between survivability and the depth of coverage required. The platform could be a manned aircraft, RPV, drone, helicopter or aerostat. Limitations tend to occur in the case of SAR where there are performance/implementation advantages in the use of relatively high-speed platforms.

- Since the sensors are located over friendly territory and generally will have dedicated ground terminals as part of the sensor system, the data links can probably be protected from ECM.

- Because these sensors view targets at long ranges, they generally can be jammed by a determined enemy. There are two basic forms of barrage

*Respectively 3^{o} and 6^{o} terrain masking angles assumed. Masking may be somewhat less of a problem for MTI which maintains continuous observation and which will, therefore, either due to sensor or target movement, observe a given target from a variety of aspects.

noise jamming* of concern to standoff sensors which use directional antennas. Sidelobe jamming describes the case where an enemy illuminates the sensor receiver with sufficient energy to reduce performance in all directions; this must be a large and directive jammer which then itself becomes a lucrative target. Mainlobe jamming only attempts to reduce the sensor performance when the sensor's directional beam is pointed toward the jammer; a few relatively small jammers can be used to block observations over a sector and the sensor's only recourse may be to operate at shorter ranges. In general, good system design can be expected to minimize the threat from sidelobe jammers but mainlobe jamming must be carefully evaluated for each system implemtation.

The following subsections discuss the principal performance advantages and limitations of each of the four long-range standoff sensor types.

A. *Synthetic Aperture Radar (SAR)***

A synthetic aperture radar (SAR) maps the ground, typically with a resolution of a few meters. A SAR map, based on differences in radar reflectivity, will usually show terrain variations such as forests, meadows rivers and ponds and man-made features such as towns, airfields, bridges, plowed land and roads.

SAR can be viewed as equivalent to long-range, all weather, photo reconnaissance with resolution sufficient to separate targets or image large, fixed-type targets (e.g., bridges, airfields), but generally not adequate to image individual, truck or tank-sized targets. Skilled

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*Deception jamming must also be considered.
**SAR is distinguished from SLAR (Side Looking Array Radar) which could also be a SAR but which more often refers to a side-looking, MTI mapping system.

interpreters can recognize distributions and patterns typical of many tactical targets or target arrays in much the same way that photo interpreters do. Some relevant characteristics of SAR sensors are as follows:

- Basically maps the targets and background with "high-resolution" (order of a few meters) in both range and cross-range. Vehicle targets will appear as blobs and the resolution is adequate for direct recognition only in the case of targets quite a bit larger than a single vehicle. (Interpretors may recognize vehicles from their context or patterns of distribution.)

- Conventional SAR usually observes in a fixed direction relative to its platform* (typically broadside) and relies on the aircraft motion to sweep out a swath. This is depicted in Fig. 1(a). The result is a rolling stripmap of the area the sensor is passing. Any given area is observed only once on each pass of the sensor (periodic revisit as opposed to continuous surveillance).

- The interpretation of the data is manual-intensive in much the same way that photo data is. The problem is that there is too much data and no easy way to provide "bulk filtering" or automatic processing to reduce the volume of data to more manageable proportions. There is a mass of data, very little of which is target related; the returns, for the most part,

*SAR can be implemented with an electronically scanned beam and provided with a scanning/mapping mode. The limitation there is a tradeoff between resolution and scan extent/time.

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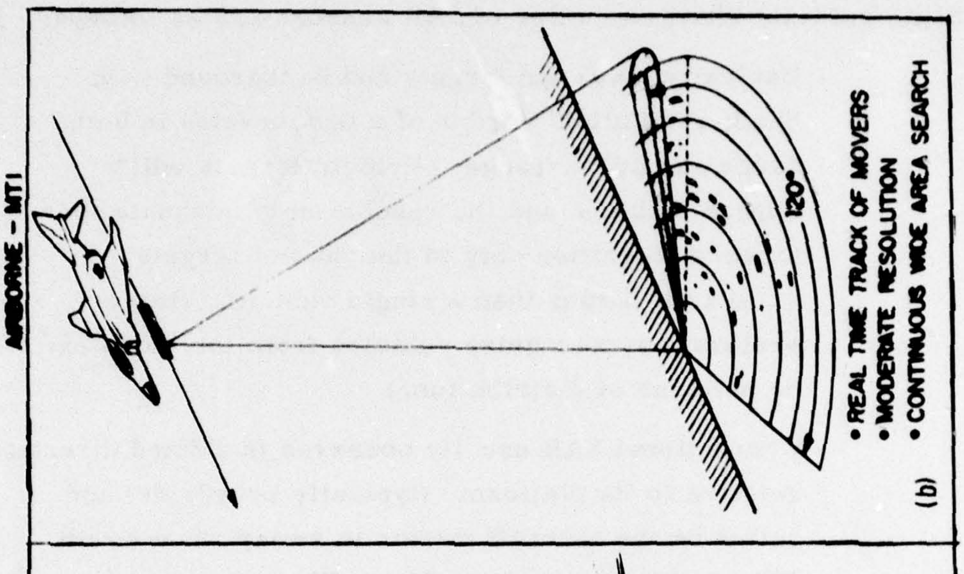

Figure 1

arise from objects which were there last week and will be there next week also. The next two items below, discuss prospective methods for dealing with this problem.

- Change detection techniques may be used to automatically highlight changes in the scene between passes of the sensor. In essence, the data of the current pass are compared (resolution element by resolution element) with those of the previous pass and changes are noted. This is a "moved" target detector as opposed to the conventional "moving" target detection.

  Reasonable probabilities of detection and false alarm will be achievable but some false alarms will always be expected as a result of physical changes in the clutter (e.g., rain, wind) from pass to pass. In addition, it should be noted that many of the moved or moving vehicles will be detected; there is no inherent mechanism to correlate such detections on one pass with those on the next because of the relatively low data rage. Because of this, confusion is likely in observations of areas with high ambient levels of moving vehicles (e.g., Central Europe).

- It may be possible to develop signal processing techniques for use with SARs, such as those developed for FTI radar (see Sec. III-6), which would detect, on a single pass, all man-made, metalic targets not obscured by foliage. This would permit the generation of SAR maps with overlays showing the location of such targets, thus radically speeding the interpretive process.

- The SAR system can be arranged to keep a limited small area (order of 1 km x 1 km) under observation as the sensor passes ("spotlight SAR mode") while retaining the inherent resolution. During this process, the swath mapping capability will be lost.
- The frequencies generally required for practical longer-range SAR will not penetrate foliage. Hence, targets which are under foliage will not be observed and targets which, between passes, have moved from trees in one area to trees in another will not be detected.

SAR images provide an excellent mechanism for detailed examination of an area of interest. An interpreter studying successive passes can, for example, locate and identify new installations or assembly areas.

B. MTI Radar

MTI radar utilizes the ability of a radar to measure target doppler* to distinguish those targets which are moving from the targets and background which are not. Because this sorting is an automatic process which requires fairly short integration times and hence can be repeated frequently, the MTI radar is capable of maintaining continuous surveillance of the targets which are moving in a large area**. MTI and SAR are quite complementary sensors. Some relevant characteristics of MTI radars are as follows:

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*The doppler measurement capability is utilized in the SAR to achieve the high resolutions while in the MTI radar it is used to filter out a class of targets of interest (those which are moving). The basic radar could be the same with different forms of processing so it is quite practical to construct a dual-mode radar. However, the missions of a strip-mapping SAR and a surveillance MTI are generally not compatible in terms of the operation of the sensor platform so such a sensor, with this particular dual mode capability, may well not be desirable. On the other hand, the complementary nature of spotlight SAR and MTI make this latter combination attractive.

**The doppler resolution required in a SAR radar to separate targets, located in different parts of the antenna beamwidth, according to their different doppler shifts induced by platform motion, is typically an order of magnitude or more greater than that required to detect moving targets in ground clutter in an MTI mode. Hence, much longer integration times are required and the target revisit rate is correspondingly reduced. See Fig. 1(b)

- This continuous and rapid coverage provides a picture of enemy activity and movement patterns. Because only the movers are reported, the volume of data is manageable and the history, for say 30 minutes, can be preserved in rapid access memory. This permits the fast display of the history* which has been found to be quite useful in understanding activity and traffic patterns.
- MTI data are amenable to automatic processing by digital computers. For example, it is entirely feasible to automatically filter the data by area, direction and speed to reduce display complexity; traffic counts can be provided in certain directions or along particular routes. Convoys (or group movement) can be detected and automatically tracked.
- Like SAR, tactical MTI radars will generally have no foliage penetration capability.
- MTI is particularly suited to second echelon targets which tend to move at speeds of 10 m/sec or greater. Such traffic would have a high probability of detection by MTI radar which, even though screened by terrain or foliage at times, will see the targets on visible portions of roads because of its ability to continuously observe areas with rapid updates.
- The ability to continuously observe motion over a large area may provide the only certain form of IFF if a target group, once identified, can be tracked and its identification preserved.

*The display of history is a form of tracking; more conventional track and prediction may prove even more useful.

- MTI alone does not have a capability for target classification except as the map context or nature of the motion provides it. The vehicle spacing, uniform velocity, lack of passing and the like will aid in recognition. Generally, military formations are recognizable as such but the distinction between a convoy of tanks and a convoy of trucks is probably not possible.

- The accuracy of target location is limited to some fraction (usually 0.1 - 0.01) of the real beamwidth of the radar and will be typically 200 m x 20 m at ranges of 200 km* and proportionately better at shorter ranges.

- MTI is unable to track or observe targets which stop. The history, however, can retain a memory of where and how many targets stop in any area and may furnish important clues for location of supply areas, marshalling yards, command posts and the like.

- A spotlight SAR is an obvious and important auxiliary mode for an MTI radar because of the previous item. Spotlight SAR permits the detailed examination of areas in which targets disappeared. This form of SAR is readily implemented in an MTI radar.

C. Foliage Penetration Radar

In heavily forested regions, radars without the capability to observe targets under foliage cover may be seriously limited in their ability to provide a picture of the battlefield. In order to penetrate more than a very small amount of foliage, a radar must operate at a frequency of about 500 MHz or lower. Having decided to go to this low frequency range, the designer can build either SAR or MTI radar but there are serious limitations which result from the choice of frequency.

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*1 beam with 15:1 beamsplit.

- Detection of stationary targets at long ranges is difficult because of requirements for very long integration times (to achieve high resolution) or acceptance of quite poor resolution. The improvements in inertial platforms and processing may partially offset the problems in a decade or so but it is still doubtful that long-range, foliage-penetration SAR will be practical.*

- MTI provides an inherent mechanism for discrimination against natural clutter and, therefore, should be designed at the highest frequency which will penetrate foliage (e.g., 225 or 425 MHz)**. MTI may be practical to ranges of about 150 km but fairly large antennas (e.g., 15 m) will be required and this, in turn, will dictate the use of large aircraft as sensor platforms (e.g., Boeing 707). Because these systems are necessarily large and expensive, they would present lucrative and probably vulnerable targets. Alternatively, it might be possible to develop an adaptive array or some other innovative approach.

- Because of the low frequency and consequent large beamwidths and small available bandwidths, these systems are very susceptible to jamming.

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*Integration times will still be limited by the so-called "range-walk" problem and lower frequency SAR will therefore be restricted to relatively coarse resolutions. At frequencies above about 100 MHz, tactical targets and natural objects (e.g., tree trunks) have about the same radar cross section and, with the coarse resolutions available, the resulting mapping is of limited value. Below 100 MHz, there is a "natural filtering" and tactical targets will dominate the radar scene. For this reason, foliage penetration SAR will probably operate below 100 MHz. However, at these frequencies, multipath losses are severe (6-20 dB) for targets 1-1.5 m above the ground and larger systems or high depression angles (i.e., short ranges) will be required.

**There is some uncertainty whether frequencies above 300 MHz are suitable. It may well be that multipath losses are sensitive to changes in foliage constituents. Because of a lack of experimental data at depression angles below 20°, the performance degradation this would introduce is not quantifiable.

D. Emitter Location Systems

Emitter location systems (ELS) designed for use against deliberate hostile RF radiations such as radars, communications or jammers, can be based on either direction of arrival (triangulation) or time of arrival* (multilateration) approaches or both. Such sensor systems can provide the locations of radiating targets and, generally, at least the classification of these targets.

- For standoff ranges, a multiple-station sensor system (three or more) will be required to achieve reasonable accuracies.

- An ELS can provide continuous coverage of a very large area and can locate and classify the emitting targets in this area.

- ELS data would be automatically processed by computer in real-time (lags of seconds) with direct digital reports of locations/classifications.

- Location accuracies are generally excellent for almost any purpose (tens of meters). However, the performance may be greatly degraded by enemy use of deception or cover signals.

- The actual sensors are passive and, therefore, covert. However, a significant number of data links are involved (the number and type depend on the particular system configuration). Attention must be given to these to maintain covertness and ECCM capability.

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*Meant to include time of arrival (TOA), time difference of arrival (TDOA), differential doppler (DD) and any other similar techniques.

- The targets which are located are the radiating antennas. At least for some of the emitters, the antenna can be remoted and easily replaced and this tactic might defeat the ELS working alone. However, in conjunction with another different type of sensor (e.g., SAR), this may be only a nuisance.

- In some cases an ELS designed against some classes of emitters, may be confused and degraded by high emitter densities. In such instances, smaller area coverage (i.e., shorter range) may be desirable.

E. Complementary Standoff Sensors

It is obvious that the three basic forms of standoff sensor (SAR, MTI, ELS) are complementary. Each has its strengths and weaknesses but the three together provide a capability that is difficult to escape or to defeat except by physical attack or exceptional jamming. A few examples of the potential of pairs of these follow:

- SAR/MTI provides a means of examining fixed targets where motion history indicated accumulations of stopped vehicles or suggests installations of interest such as command posts or assembly areas. Conversely, it provides a mechanism to monitor the dispersal or motion of previously classified fixed targets.

- SAR/ELS. Using the location of emitters as cues permits detailed examination with the SAR with some foreknowledge of the types of equipment being probed. This should both alert the interpretation and greatly aid the interpreter.

- MTI/ELS. Some of the emitters tend to be associated with movement and this provides a good tool for associative classification. For example, the mobile AAA accompanying tank formations is radar-equipped; communications between units in motion must be by radio rather than wire.

It is worth noting that both MTI and ELS can be implemented with fully automated processing. The correlation of motion history for a few hours and emitter observations over that period should be capable of providing an excellent picture of the battlefield. Since both sensors can be computer processed, the correlation and at least first-order interpretation can also be automatic, so the picture could and should be updated in real time without manual intervention. This real-time data can then be overlayed on either a cartographic or SAR map.

III SHORT-STANDOFF (1-10 KM), PENETRATOR OR ATTACK

The Short-range standoff, penetrator surveillance and attack system sensors are generally similar although the latter obviously may have direct coupling to weapon delivery systems. From the point of view of sensor possibilities and limitations, the three applications are not significanly different.

At these shorter ranges, the variety of possible sensor capabilities expands considerably. Sensor jamming vulnerability is generally much less of a problem but the protection of data links is more difficult. The platforms might include all those discussed in Section II plus the mini-RPV and even missiles or artillery shells in some cases. While it is easier to provide good sensor capabilities* (given enough altitude for line of sight), it presumably places the sensor platform in more jeopardy.

The sensors which will be discussed in this category are as follows:

- Imaging Sensors (primarily optical but also, potentially, very high resolution SAR)
- SAR, MTI radar, foliage penetration, ELS (similar to those discussed for longer ranges)
- FTI (Fixed Target Indication) Radar
- Unintentional-Emitter Location
- Others (a few possible but not likely sensors)

The following subsections deal briefly with each of these.

A. Imaging Sensors

Imaging is used here in a fairly narrow sense, implying a television-like presentation of vehicle sized targets. Similar depiction of larger targets (e.g., bridges, airfields) was termed "mapping" (this use of these terms is not general).

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*The principal exception is area coverage.

Imaging sensors will usually present the target image in some form for viewing and interpretation by an observer. It may be possible, for at least high-contrast images, to develop automatic recognition schemes. However, the difficulty of this automated interpretation for air-to-ground applications with tactical backgrounds and natural contrast variations, should not be underestimated.

In general, imaging sensors must be cued in some manner to the target array of interest. Typically, such sensors must have narrow fields of view.

At least in many cases, the data link bandwidths required with imaging sensors are likely to be high with the resultant difficulty in protecting the link from jamming. The maximum possible automatic, on-board processing is desirable to alleviate this problem.

There are at least four separate sensing regimes which can provide imaging. These, and comments relating to each are as follows:

- Electro-optics (EO)*. This includes primarily TV and its variations such as LLLTV, CCD equivalents, etc. The E-O sensors are subject to well recognized weather limitations and, without auxiliary illumination or use of an active (laser scanned) system, are useful primarily in the daytime.**

- Passive Infrared (IR) exemplified by the FLIR*** class of sensors. IR generally has better weather penetrability than the visible but is still somewhat limited in adverse weather; IR sensors operate day or night.

  The IR sensors observe the thermal emission characteristics of the targets and thus provide useful data beyond that found in the reflected characteristics in the visible sensors. For example, a truck which has

*Defined as visible and near IR.
**LLLTV performs well in moonlight and, of course, any of the E-O systems can work with artificial illumination (e.g., flares).
***FLIR (Forward Looking IR) has come to refer to any high resolution, imaging IR (the IR equivalent to TV).

been operating recently should be readily distinguished from one which has not.*

- Active IR. An IR radar can provide similar imaging capability to that of the passive IR but with very significantly improved weather penetration; it should, in fact, be capable of "all weather" operation as long as the sensor operates below the clouds. The active IR senses the reflections as does a conventional RF radar and such a system would normally be designed with a passive mode as well, to take advantage of the complementary information in the passive thermal signature.
- A very high resolution SAR can be constructed to provide imaging resolution of a target but the image will generally not be useful for recognition because of the scattering properties of radar wavelengths. It may be possible in future developments of signal processing techniques to overcome these limitations and provide a SAR imaging which allows direct target recognition.

B. SAR, MTI Radar, Foliage Penetration Radar, ELS

These sensors were all discussed in Section II as longer-range devices. The same capabilities and, for the most part, the same limitations apply at the shorter ranges. In general, the difficulties of sensor design are mitigated by the shorter ranges and the capabilities can often be improved in degree.

*Because the IR provides unique signature information about the target, it appears possible to develop a non-imaging, automatic processing form of IR surveillance which will detect and broadly classify targets.

Two distinctions from the previous discussion are worthy of note:

- Foliage penetration SAR or MTI is probably practical at these ranges.
- A single sensor ELS is possible for operation against at least some classes of emitters with relatively coarse location accuracy. In this form of system, a DOA sensor would make successive bearing measurements as it flew by and these would provide location by triangulation.

C. FTI Radar

At these shorter ranges, a narrow beam radar can provide mapping resolutions without complex, synthetic aperture processing. This permits a variety of processing options for target detection and, in the case of some target types, perhaps recognition, by automatic processing.

An FTI radar can provide a SAR-like map to a human interpreter. More importantly, it would automatically provide the locations of all fixed, man-made, metallic targets of vehicle size or larger, either with or without the accompanying background map. This is the equivalent of MTI but for the non-moving targets. The FTI radar is inherently capable* of providing high-quality MTI as well.

The FTI radar can perform its mapping and automatic, real-time detection functions while continuously scanning and searching moderate sized areas with rapid updates.

D. Unintentional-Emitter Location

A number of tactical targets emit RF radiation by the nature of their operation. For example, the ignition system of a vehicle engine generally radiates and rotating electrical machinery such as a generator might be expected to do likewise. At short ranges, a directional sensor system can be built to provide a bearing or location (by triangulation).

*If designed for coherence.

E. Others

The sensor types discussed above are probably the important ones. A few other possibilities, however, deserve at lease some mention.

- METRRA (MEtal Target Re-RAdiation): A special purpose radar (mismatched for conventional radar applications) is capable of detecting most complex, metallic targets. Detection through foliage and even under thin layers of earth is possible. There are two major drawbacks; (1) the equipment would be quite large (helicopter borne) and operate at maximum ranges of the order of a kilometer; and (2) targets as diverse as rifles, jeeps and tanks would provide approximately the same indications.

- RF Radiometry: A passive RF sensor can map the terrain with relatively coarse resolution (perhaps a few tens of meters) and, with this resolution, can provide a photo-like mapping in almost all weather and at night. From ranges of 1 km or greater, vehicle-sized targets would generally not be detected* so, for target detection, this has application primarily to bridges, airfields and larger installations.

- Acoustic, magnetic, chemical and nuclear sensors probably have limited utility at these ranges. However, there may well be interesting exceptions.

*A slow platform with fairly large antenna (to provide angle resolution) and long integration times, may be able to provide surveillance of vehicle-sized targets at ranges of approximately a kilometer.

IV IMPLANTED SENSORS

There is a broad experience base with implanted sensors and no attempt will be made here to review or summarize that work. Some of the sensors which have been built or considered are:

- E-O (passive)
- IR (passive
- RF active (in a sense, MTI)
- RF radiation detectors
- Acoustic
- Seismic
- Magnetic
- Chemical
- Nuclear

and probably others. These may be designed or combined to detect personnel or vehicle activity; to verify classifications of supply, assembly or CP areas; to locate artillery; to listen to what is going on and for many other purposes.

Sensors may be implanted by air drop, artillery, or by hand in the case of withdrawal. They generally have sensing ranges of the order of 100 m although this obviously varies widely with the type.

There are at least two general problems/characteristics of implanted sensors which should be noted:

- The data link for reporting observations must be protected from detection and jamming and this is difficult to do. A relay aircraft (or other elevated platform) is required for line of sight.
- The accurate measurement of the sensor positions is at least difficult within the other contraints on design.

These sensors can provide valuable information which is not available in any other way and, in conjunction with standoff surveillance sensors, may provide recognition or verification.

V TERMINAL HOMING

Strictly speaking, terminal homing is not part of the target detection, location and recognition job. On the other hand, the first and probably most important function of an autonomous terminal guidance sensor is to detect and locate the target and to discriminate it from the background. In many cases, the terminal homer will be faced with reacquisition of a target originally observed by a surveillance sensor but the technical aspects of the problem are not significantly different than those associated with surveillance acquisition*. For terminal homing, the processing must be autonomous and automatic or there must be a data link (very vulnerable to jamming in this case) with a man in the loop**.

Without going into the special properties of sensors in this role, let it suffice to point out at least some of the sensor techniques, already discussed, which may have application in terminal homing.

- Homing on intentional RF radiation (e.g., Anti-Radiation Missiles)
- IR non-imaging (footnote under "IR" in Section III-A)
- FTI radar (Section III-C)
- IR or E-O imaging with automated target recognition (Section III-A)
- Acoustics

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*Closer ranges simplify the detection and recognition but the generally less capable sensors make it more difficult.

**This discussion primarily deals with autonomous, target-observing seekers. The very important class of semi-active seekers (i.e., laser or microwave designation homers) is not included.

VI SUMMARY

Table I summarizes the applicability of the various classes of sensors to each of the principal surveillance range domains.

TABLE I

SENSOR SUMMARY

	Ranges 10 - 200 KM	Ranges 1 - 10 KM
General	Broad area coverage Less vulnerable to physical attack Data links can be protected. Sensors are more susceptible to jamming	More detailed information Sensors less easily jammed Data links more easily jammed Less problem with terrain masking
Imaging Sensors	—	Image presented to operator for interpretation Some possibility of automating recognition Wideband data links particular problem against jamming Could be TV, passive IR, active IR or possibly SAR
Non-Imaging IR	—	Possible automatic processed target detection and limited classification
Passive RF		
Intentional Radiation	Multiple station sensor system Continuous large area coverage Detects and classifies emitting targets (actually locates the radiating antenna) Real-time reporting with completely automatic processing Covert system possible Excellent location accuracy	Same as long range except: Possible single station systems (coarse location accuracy)

TABLE I (Continued)

	Ranges 10 - 200 KM	Ranges 1 - 10 KM
Passive RF	—	
Unintentional Radiation		Bearings or triangulation Engine ignition or generator radiations
RF Radiometry	—	Mapping No detection of vehicle sized targets
Active RF		
SAR	Maps with resolution of few meters Fixed or transient targets Vehicle-sized targets are blobs Periodic revisit No foliage penetration Manual-intensive interpretation but possible automatic processing techniques to aid interpreter	Same as long range except: Foliage penetration SAR possible as separate special sensor Less masking problems
MTI Radar	Continuous wide area search with rapid update Reports moving targets only Motion history analysis Real-time reporting with completely automatic processing No foliage penetration except for special, large system Moderate location accuracy	Same as long range except: Better location accuracy Less masking problems Foliage penetration with smaller system

TABLE I (Continued)

	Ranges 10 - 200 KM	Ranges 1 - 10 KM
FTI Radar	—	Automatic detection of fixed and moving targets Continuous search over moderate sized areas Mapping of search area while scanning and performing detection functions
METRRA	—	Metal detection Large sensor system No discrimination capabilities
Acoustic, Magnetic, Chemical, Nuclear	—	Possible utility

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AGARD Project 2000 is examining the match of military requirements and technology for use about the end of this century. As a part of this effort, Study Group #3 headed by John Entzminger of RADC, is undertaking a dialog on target detection, location and recognition between representatives of the operational military users and sensor technologists. The objective is to consider military needs and prospective technological capabilities to jointly speculate on the most valuable system forms for development. This paper was prepared to aid the discussion and attempts to: summarize the user aspects of current sensor technology, suggest some directions in which sensor capabilities might be developed, and point out the capabilities and limitations of the generic sensor forms.

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